Seabed Geo-Acoustic Model and Scattering Model from Low Frequency Measurements in Shallow Water

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LONG-TERM GOALS

The long-term goals of this work are: to develop a practical seabed geo-acoustic model and a practical scattering model for predicting sound transmission, reverberation and their spatial coherence in shallow water (SW).

OBJECTIVES

The scientific objectives of this research include: (1) To characterize sea bottom geo-acoustic parameters (sound speed and attenuation) and bottom scattering function from both sound propagation and reverberation, measured in a low frequency (LF) range of 50-2000Hz. (2) To reveal the physics of the LF field-inverted seabed geoacoustic model and bottom scattering function (vs. angle and frequency).

APPROACH

The seabed has been the *king* of the SW acoustics problems. Much progress has been made in our understanding of seabed acoustics through significant efforts on seabed acoustic modeling and geoacoustic inversion. However, there remain important unanswered questions and a scarcity of high-quality basic research data sets. For example, the debate over the sound speed dispersion and the frequency dependence of sound attenuation in sandy bottoms has persisted for decades. There is a lack of high-quality wideband data of seabed sound speed and attenuation that covers the low- to high-frequency transition band (from low hundreds of Hz to several kHz). Many geoacoustic inversion papers have been published with different algorithms. However, these inversion methods have yet to produce a fully populated wideband data set of bottom sound speed and attenuation for practical sonar applications and sediment acoustic modeling. There are research gaps between seabed geoacoustic inversions and sediment acoustics modeling. This work first analyzes and summarizes the field measurements conducted at different locations to derive sound speed and attenuation for sandy and silty seabottoms in a frequency range of 50-2000 Hz. Then, the LF field-inverted sound speed and attenuation are used to compare with physics-based seabed geoacoustic models and to estimate possible ranges of physical parameters for those models. The LF field-inverted compressional speed and attenuation are also used to estimate a possible range of the shear wave speed and attenuation in the top layer of the sand-silt bottoms.

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LF small angle seabed scattering is nearly impossible to directly measure in shallow water, because of multipath propagation interference and time-frequency resolution limitations. This work attempts to deduce the small angle seabed scattering strength vs. angle and frequency from SW long-range reverberation. It is based on three previous works of the author: (i) The analytical (closed-form) expressions of SW reverberation [Zhou, (Chinese) Acta Acustica, **5** (2), 86-99 (1980) and Zhou et al., Chin. J. Acoust. **1**, 54-63 (1982)]; (ii) the LF field-derived seabed geo-acoustics model [Zhou et al., J. Acoust. Soc. Am., 125(5), 2847-2866 (2009)] and (iii) A quality database of wideband reverberation level normalized to source level [Zhou and Zhang, IEEE J. Oceanic Eng., **30** (4), 832-842 (2005)].

RESULTS

(1) The seabed attenuations, inverted from different acoustic field characteristics at 20 locations in different coastal zones with sandy (and sand-silt mixed) bottoms, exhibit similar magnitude and nonlinear frequency dependence below 2000 *Hz*. The bottom attenuation can be expressed by

$$\alpha\,(dB/m) = (0.37 \pm 0.01)(f/1000)^{(1.80\pm0.02)} \qquad \text{for 50-1000 Hz.}$$

$$\alpha\,(dB/m) = (0.35 \pm 0.01)(f/1000)^{(1.78\pm0.02)} \qquad \text{for 50-2000 Hz}$$

(2) The LF field-derived sound speed and attenuation in the bottoms can be equally well described by the Biot-Stoll model, the Buckingham VGS model, the Chotiros-Isakson BICSQS model, and the Pierce-Carey model. These four models with different physical mechanisms in consideration may result in almost identical non-linear frequency dependence of sound attenuation in sandy seabottoms (that is consistent with the results reported in this research). A possible range of physical parameters for these four models has been estimated from the LF field-inverted sound speed and attenuation. For example, for the Biot-Stoll model, the porosity β is in a range of [0.45, 0.39], and the permeability $\kappa(m^2)$ is in a range of [0.5E-11, 2.5E-11]; the other 11 Biot parameters are assumed the same as those from the SAX99 measurement [Williams et al., IEEE, JOE 27, 413-428(2002)].

(3) The frequency exponent of the LF field-derived sound attenuation in the sand-silt bottom is less than two. Carey et al. suggested that this was caused by neglecting the shear wave effects in the geoacoustic inversions [JASA 124, E271-E277, 2008]. If this assumption is correct, correcting the frequency exponent of the sound attenuation from 1.81 to 2.0 may result in paired shear wave speed and attenuation values in the top layer of the bottom for 50-500 Hz. The average shear wave speed is in a range of 77.3-158.4 m/s; the shear wave attenuation is in a range of 8.0-1.0 dB/λ. Figure 1 shows that a frequency exponent of 1.81 for the LF sound attenuation is corrected to 2.0, using paired shear wave speed and attenuation values ($c_s = 116 m/s$ and $\alpha_s = 3.0 dB/\lambda$). Figure 2 shows possible combinations range of paired hear wave speed and attenuation in the top layer of sandy seabottoms.

(4) Reverberation level and vertical coherence have been analyzed from the measurements at three experimental sites. The data will be used to characterize the LF bottom scattering function vs. angle and frequency, and to reveal the physics of the LF bottom scattering.

(5) In general, the SW reverberation is dominated by the bottom scattering. However, at some ranges and some frequencies, the water volume scattering contribution may occasionally be larger than the contribution from diffuse bottom scattering. Figure 3 shows that in shallow water with a strong thermocline, around 20-23 seconds after the explosive sources were denoted (range about 15-16 km from the source), the reverberation data exhibit strong water volume scattering between 1000 and 3000 Hz with a peak around 1500 Hz. It is about 7-10 dB higher than the diffuse bottom scattering reverberation from the same range. The mechanism of the observed volume resonant scattering is unknown; it might be caused by fish group, internal wave packages and so on.

IMPACT/APPLICATIONS

The LF field-derived seabed geoacoustic model can be used for sonar prediction and sediment acoustics modeling in shallow water.

PUBLICATIONS

1. J.X. Zhou and X.Z. Zhang, “Physical parameters for four seabed geoacoustic models from low-frequency measurements,” in *Shallow-Water Acoustics* (AIP Conference Proceedings 1272), 163-172 (2010).
2. L. Wan, J.X. Zhou and P.H. Rogers, “Low-frequency sound speed and attenuation in sandy seabottom from long-range broadband acoustic measurements,” J. Acoust. Soc. Am. 128 (2), 578-589 (2010).
3. J. Simmen, E.S. Livingston, J.X. Zhou and F.H. Li, <*Shallow-Water Acoustics*> (AIP Conference Proceedings 1272), 2010.
4. J. Yang, J.X. Zhou and P.H. Rogers, “Data-model comparisons for sea surface waves from the ASIAEX East China Sea experiment,” in *Shallow-Water Acoustics* (AIP Conference Proceedings 1272), 149-162 (2010).
5. L. Wan, J.X. Zhou and P.H. Rogers, “Seabed geoacoustic inversion from long-range broadband sound propagation in the Yellow Sea,” in *Shallow-Water Acoustics* (AIP Conference Proceedings 1272), 270-277 (2010).

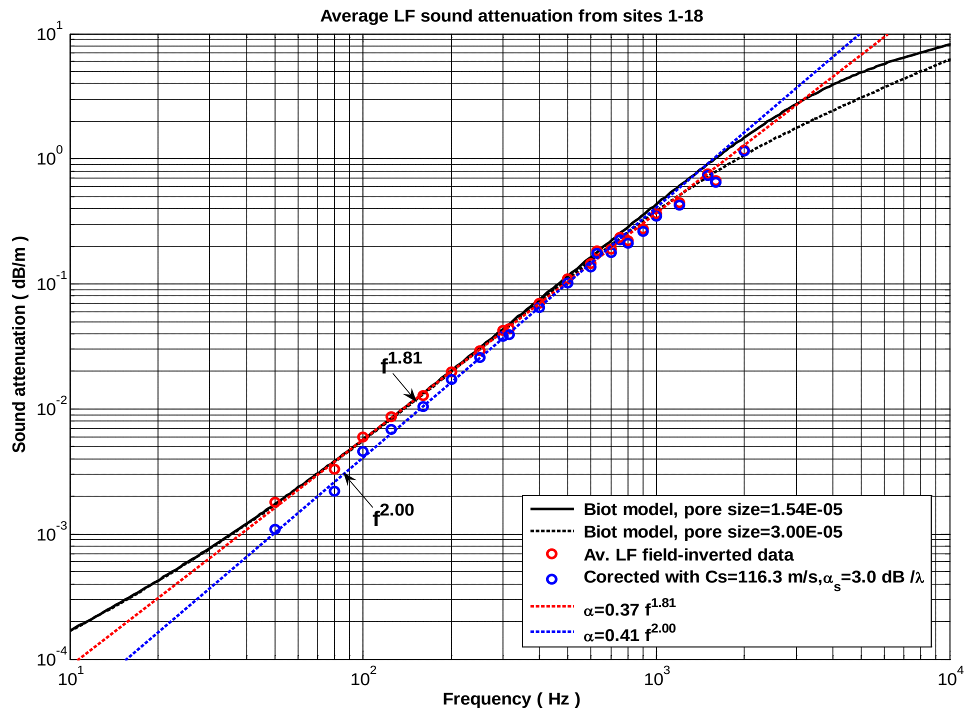

Fig. 1 The frequency exponent of the LF sound attenuation is corrected to 2.0, using paired shear wave speed and attenuation values ($c_s = 116 m/s$ ***and*** $\alpha_s = 3.0 dB/\lambda$ ***).***

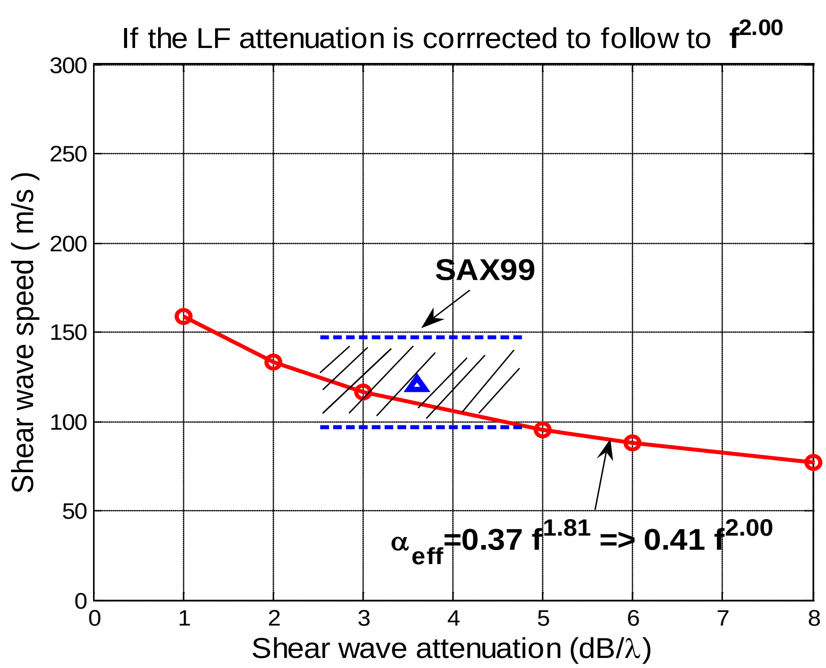

Fig. 2 A possible range of the average shear wave speed and attenuation in the top layer of sand-silt seabed in 50-500 Hz.

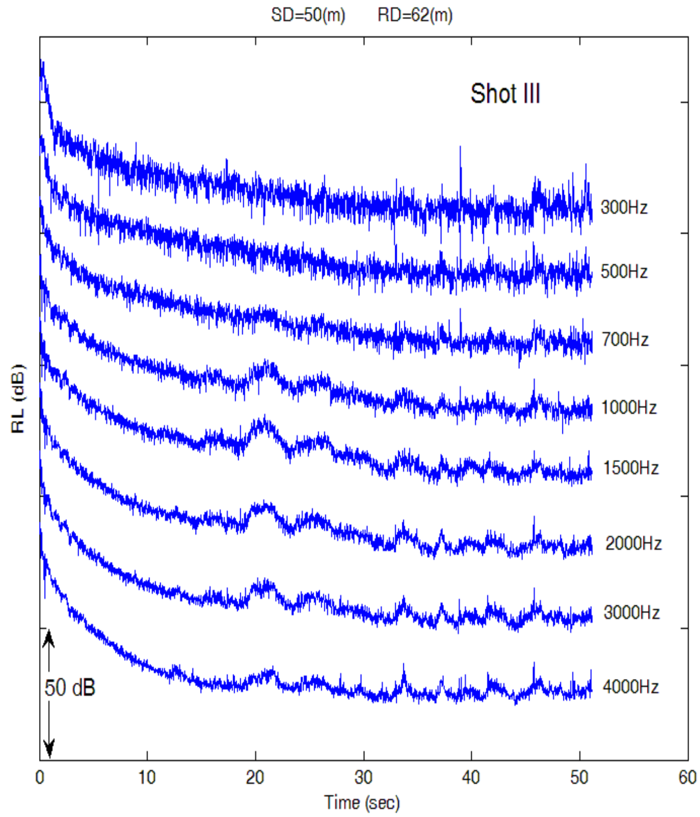

Fig. 3 The volume resonant scattering around 20-23 seconds after an explosive sources was denoted.